

Figure 4-1 Project Schedule

Starting Date

Completion Date

Legend

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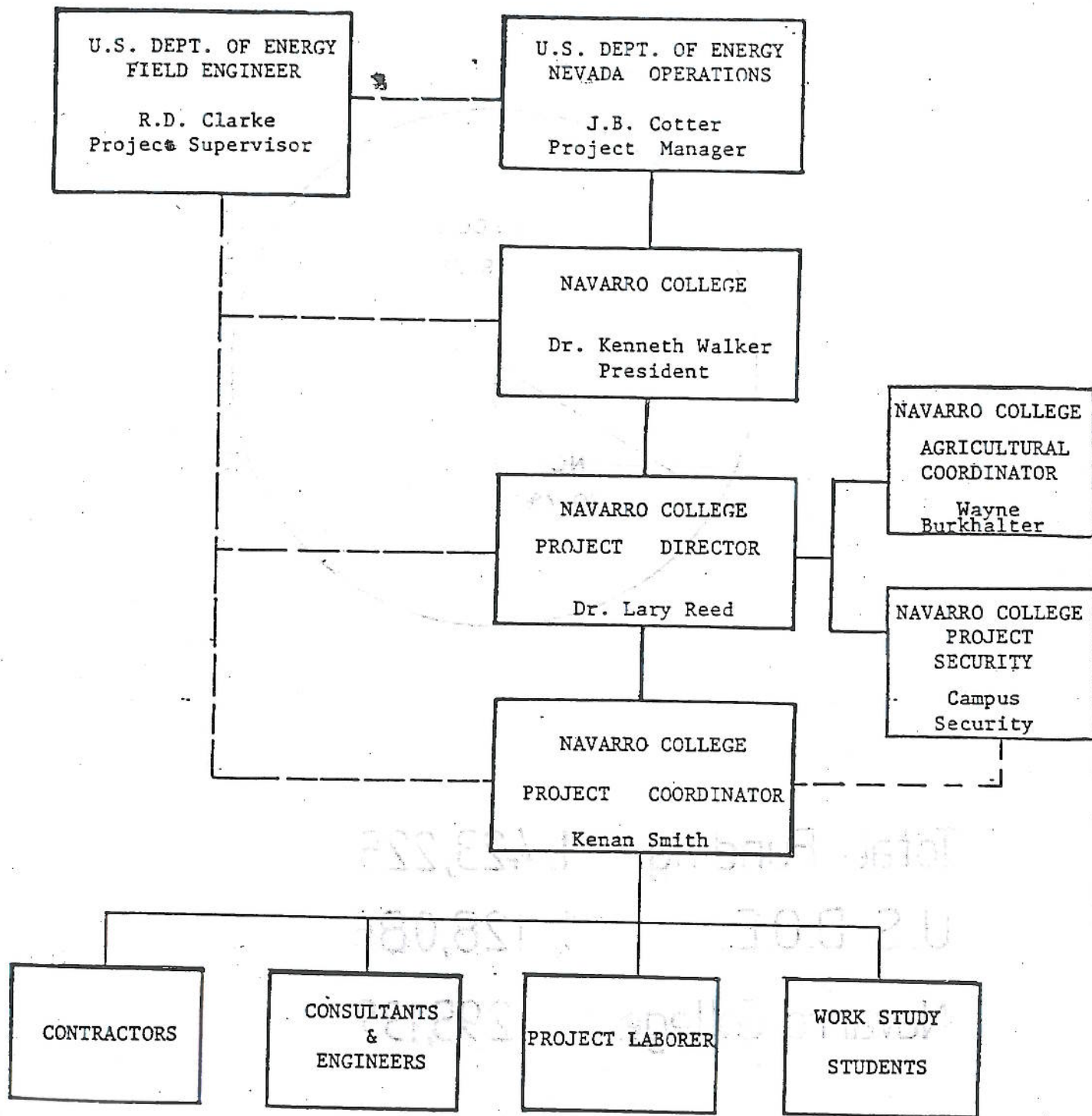
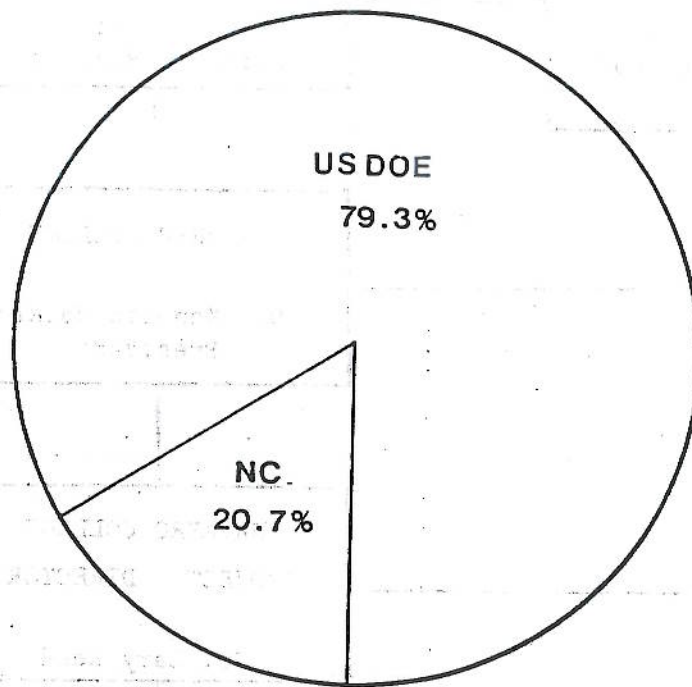


Figure 4-2
Organization Chart



Total Funding 1,423,225

U.S. D.O.E. 1,128,086

Navarro College 295,139

Figure 4-3
Cost Breakdown

5.0 RESOURCE ASSESSMENT

5.1 Pre-Project Assessment

For many years oil has been produced in and around Corsicana. Oil firms have utilized the 135°F geothermal resource from the Woodbine Formation as a supply of water for secondary oil recovery from upper zones in operational areas east of Corsicana.

5.2 Pre-Drilling Assessment

The Woodbine Formation is the shallowest unit in the Navarro County Area that contains water at elevated (greater than 90°F) temperatures. The formation occurs at a depth of approximately 2,250 feet at Navarro College. Based on a temperature log of the existing production well, the temperature of water over the perforated zone (2,450 to 2,560 feet) ranges from 116° to 119°F. The measured bottom-hole temperature is about 122°F. When the well was fully cleaned up and pumped at a flow of 330 gpm, the production zone temperature increased to 135°F.

On the basis of temperature gradient calculations, water in the deeper Trinity Group and Hosston Formation may have temperatures as high as 150° to 160°F. There are no wells completed in these deeper rocks in Navarro County.

The principal factor responsible for the high temperatures of water in these rocks is the Mexia-Talco fault system. Where the Cretaceous rocks have been downdropped along the faults, water in these units co-mingles with the hotter connate waters of the rocks in the Quachita fold belt. These downfaulted Cretaceous units are hydraulically connected by faults to the same water-bearing units on the upthrown sides of the faults. Therefore, hot

waters migrate upward along the faults and mix with water in the shallower Cretaceous units, resulting in above normal water temperatures at shallower depths. (Fig. 5-1 through 5-3)

The Texas Department of Water Resources estimates that the transmissivity of the Woodbine in Navarro County is about 2,300 gpd/ft, based on a saturated sand thickness of 23 meters (76 feet) and hydraulic conductivity of 30 gpd/ft².

There are no other water wells producing drinking water from the Woodbine Formation at the present time in central or eastern Navarro County, due primarily to the poor quality of the water. Large quantities of brine have been pumped for over 50 years in conjunction with oil production from the Woodbine east of Corsicana. Production from the geothermal well represents only a small fraction of the brine production from oil wells.

5.3 Drill Site Selection

During 1978, and prior to the establishment of a cooperative agreement with the United States Department of Energy, local citizens expressed an interest in sponsoring the drilling of an exploratory well on the Navarro College campus. It was the intent of these sponsors that the well be located on the campus so that scientific research activities could be conducted in order to determine the feasibility of using this resource as an alternative to fossil fuels for heating purposes. Since the original intent for use of this resource was to heat a campus building and the county hospital, the first well site was selected in an open area on a northern section of the campus which was located between both the hospital and campus buildings. When the project had evolved further and the hospital was sold, this site was still conveniently located for installation of the disposal well and construction of the present project.

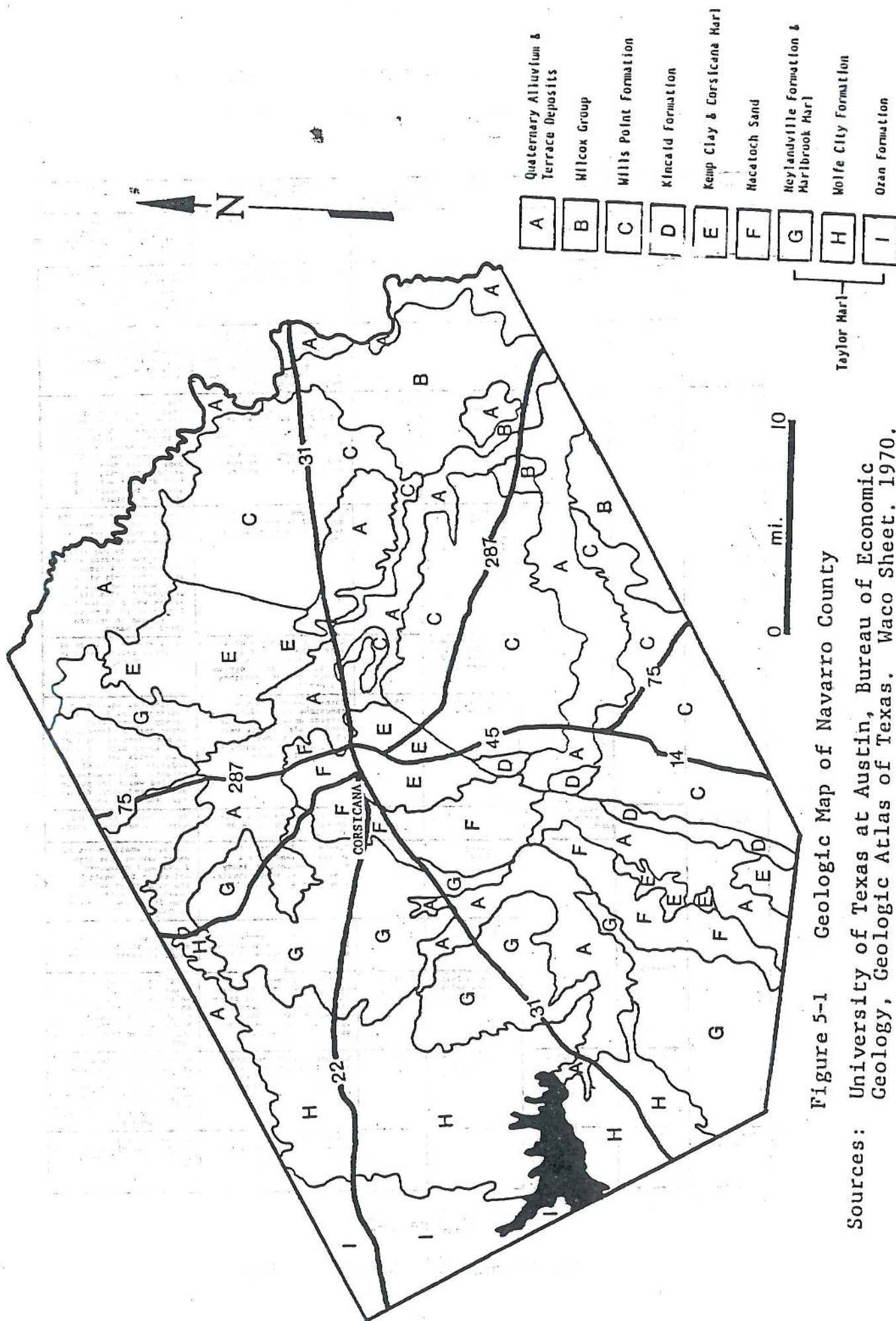


Figure 5-1 Geologic Map of Navarro County

Sources: University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas. Waco Sheet. 1970.
University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas. Dallas Sheet. 1972.

LITHOLOGY AND WATER-BEARING CHARACTERISTICS OF GEOLOGIC UNITS IN NAVARRO COUNTY

SYSTEM	SERIES	GROUP	GEOLOGICAL UNIT	MAXIMUM THICKNESS (FEET)	LITHOLOGICAL CHARACTER OF UNITS	WATER-BEARING PROPERTIES
Quaternary	Holocene Pleistocene		Alluvial deposits	55	Sand, gravel, silt, & clay.	Yields small quantities of fresh to slightly saline water to shallow irrigation wells along the Trinity River.
		Eocene	Malco	360	Fine to medium sands containing clay & silt.	Yields small quantities of fresh to slightly saline water to shallow dug wells for domestic & stock use in eastern part of county.
	Paleocene	Midway		820	Multishaded gray to black gypsiferous silty clay, siltstone, glauconitic calcareous sandstone, some sandy glauconitic limestone & concretionary limestone bed in upper part.	Yields small quantities of fresh to slightly saline water to shallow dug wells for domestic & stock use in eastern part of county.
Cretaceous	Gulf	Navarro	Nacatoch Sand	202-884	Dark calcareous, sandy, glauconitic clay, & some beds of fine to medium-grained glauconitic sandstone, above & below the Nacatoch. The Nacatoch Sand includes four sandstone lenses interbedded with light gray shale.	The Nacatoch yields small quantities of fresh water to slightly saline water to wells as much as 300 ft. deep for stock, domestic, & public supply use; & other beds of the Navarro yield very small quantities of hard water to shallow dug wells for domestic & stock use.
			T Wolf City A Sand Member L O R N A R L	1,262	Calcareous & sandy, glauconitic fine-grained sandstone, & some impure chalk.	The glauconitic sandstone (Wolf City Sand Member) yields small quantities of fresh hard water to a few shallow dug wells within the outcrop area for domestic & stock use; other beds yield very small quantities of fresh to slightly saline water to shallow dug wells for domestic & stock use in western third of county.
			Austin Chalk & Eagle Ford Shale, undifferentiated	928	Clayey limestone & chalk interbedded with silty & sandy shale, & dark shale containing beds of gypsum & thin beds of sandstone & limestone.	Not a source of fresh or slightly saline water in Navarro County.
			Woodbine Formation	592	Thin-to massive-bedded sandstone interbedded with varying amounts of shale & sandy shale. Upper part of formation contains clay lignite, gypsum, & nodules of alunite.	A principal aquifer in western third Navarro County. Water from upper part of formation is more mineralized than from lower part. Formation yields small to moderate supplies of slightly saline water to drilled wells for public supply, industry, domestic, and stock use.
		unconformity Washita and Fredericksburg (undifferentiated)		1,270	Limestone, shale, & calcareous, silty, & sandy shale.	Not a source of ground water in Navarro County.
	Comanche	Trinity	Peluxy Sand	120	Fine-grained, poorly consolidated sandstone & varying amounts of sandy clay, shale, some lignite, & nodules of pyrite.	Contains small amount of water having less than 3,000 mg/l dissolved solids in far western tip of county; but no known wells obtain water from formation in Navarro County.
			Glen Rose Limestone	1,363	Medium-to thick-bedded limestone & some sandstone, sandy shale, shale, and anhydrite.	Not a source of fresh or slightly saline ground water in Navarro County.
			Travis Peak (Pearsall) Formation	662	Coarse-to fine-grained sandstone in upper to lower parts & interbeds of sandstone, shale, & limestone in middle part. Shale & limestone increase in the middle part down-dip.	Small to moderate supplies of slightly saline water are available in western quarter of the county, but no known wells in county obtain water from the form.
	Coschulla	Nuevo Leon & Durango	Hosston Formation	289	Sandstone & sparse interbeds of siltstone, sandy shale, red & green shale, calcareous silty shale, & thin limestone.	An important potential source of small to moderate supplies of slightly saline water in western third of Navarro County. No wells obtain water from the formation in the county.
		(major unconformity)				
Pre-Cretaceous				7	Shale, quartzite, limestone, & indurated sandstone.	Oil well tests in County indicate highly mineralized water in these rocks.

Figure 5-2

*Reconstructed by Navarro College

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6.0 ENVIRONMENTAL ISSUES

Under the original contract agreement, Radian Corporation was commissioned to develop an environmental report. The purpose of this report was to investigate the planning of the project and to assure that the project would be in compliance with federal, state and local laws regulating environmental impact as set forth in the National Environmental Policy Act (NEPA) of 1969. In addition, the report was to determine the environmental documentation necessary to remain in accordance with the implemented regulations published by the Council on Environmental Quality (CEQ) in November of 1978.

The tapping of this resource does not affect normal drinking water supplies since the well is cased and cemented to a depth of 238 feet to protect fresh water aquifers.

6.1 Pre-Drill

Prior to drilling the production well, normal permitting through the Railroad Commission of Texas was sought and approved. Other State entities, such as the soil Conservation Service and the Texas Department of Geology, (Fig. 5-1 - 5-3) were also contacted to assure that drilling and utilization of this resource would not present problems in relation to environmental impacts. (See Appendix A)

6.2 Post-Drill

Once the reservoir had been located and an analysis of the water (See Appendix B) completed, the Railroad Commission required that any spent geothermal fluids, not receiving treatment for the high dissolved solids

content, be reinjected rather than elimination of these fluids through surface disposal. This requirement was satisfied through completion of an injection well in October of 1981.

The Railroad Commission was contacted on June 20, 1982 and the project scope was discussed to determine if additional permits would be required. Since the project would have a small flow and be reinjecting the spent geothermal fluid, additional permitting through the Railroad Commission was not required.

In order to determine if any other federal permits were required to meet with the environmental issues, the project was discussed with the Environmental Protection Agency (EPA) in Dallas, Texas on June 19, 1982. After reviewing the project it was determined that permitting was not required by the EPA.

Due to the high degree of design and utilization techniques employed in this system, a minimum of environmental impacts and the associated permitting requirements have been imposed on the project. The Environmental Report entitled An Environmental Report for the Geothermal Direct Utilization Project at Navarro College was completed by Radian Corporation on May 1, 1979. The results of this report can be obtained upon request from the U.S. DOE Technical Information Center.

7.0 INSTITUTIONAL ISSUES AND PERMITS

Permits required for this project were limited and did not present any significant problems. Federal permits and requirements were met through the environmental report and approval from the Environmental Protection Agency.

State permits and approvals have been supplied through the Texas Railroad Commission and the Texas Water Board Commission (see Appendix A), while normal building permits satisfied the local requirements of city and county codes.

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8.0 PRODUCTION WELL DRILLING AND LOGGING

8.1 Summary

During July of 1978 an exploratory well was drilled on Navarro College property to investigate the potential of geothermal water believed to exist in the Woodbine Formation.

The well was drilled to a depth of \pm 2664 feet and an electric log (see Appendix C) was run in the 9-5/8 inch open hole from the total depth of 2664 feet to the bottom of the 10-3/4 inch surface casing at 238 feet.

A 130°F resource was confirmed in the Woodbine Formation and the hole was cased with 7 inch casing from 2664 feet to the surface. The well was then completed with perforations in the lower Woodbine sand from 2454 feet to 2560 feet.

8.2 Completion

A 17½ inch hole was drilled to 238 feet and 10-3/4 inch casing was set and cemented from 238 feet to the surface. A 9-5/8 inch hole was then drilled from 238 feet to 2664 feet and 7 inch, 23#, K-55, R3 steel casing was set and cemented from 2664 feet to the surface (Fig 8-1).

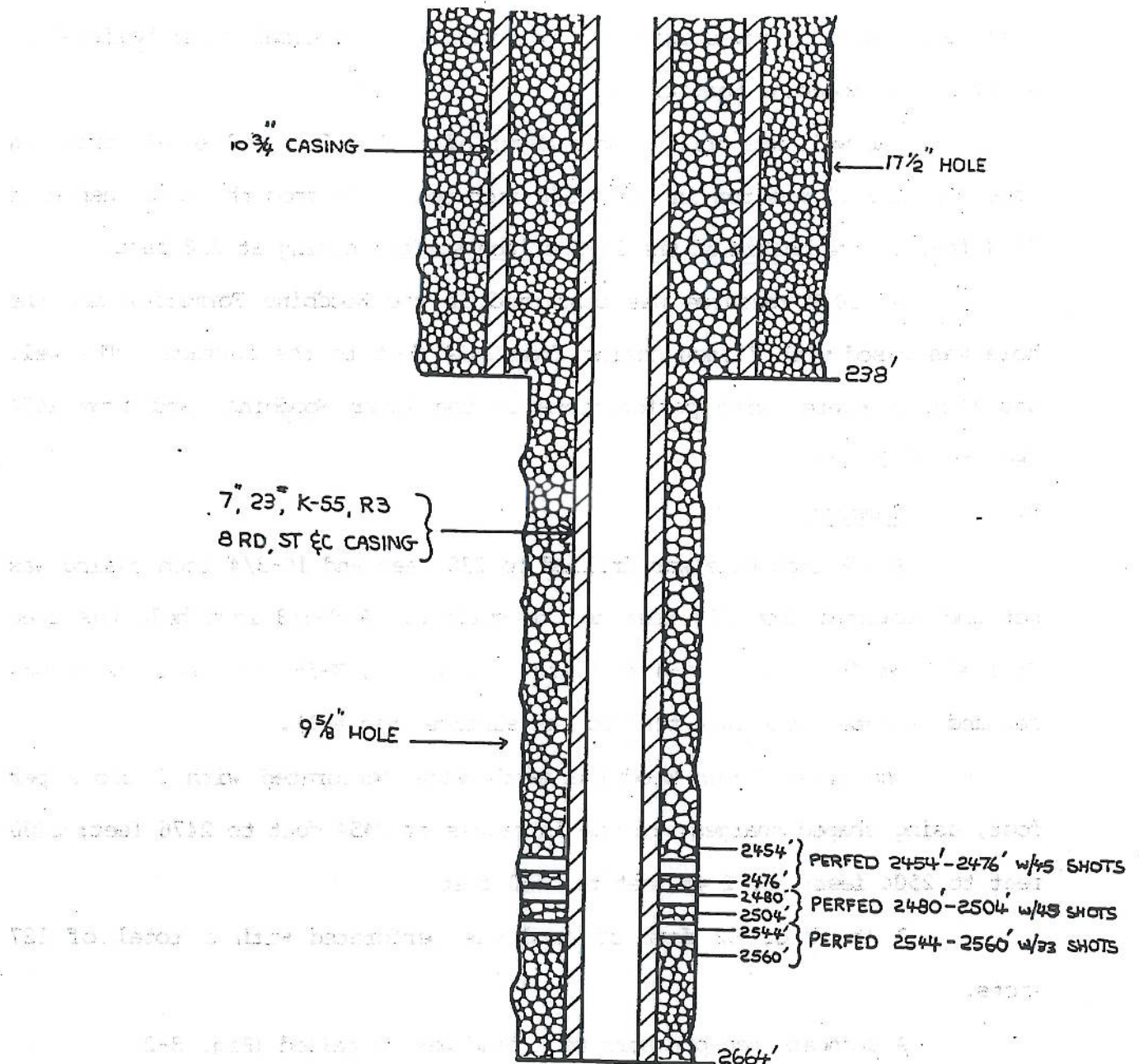
The three lower Woodbine sands were perforated with 2 shots per foot, using shaped charges, in the intervals of 2454 feet to 2476 feet; 2480 feet to 2504 feet; and 2544 feet to 2560 feet.

A total of 62 feet of sand was perforated with a total of 127 shots.

A standard non-pressure well head was installed (Fig. 8-2).

NAVARRO COLLEGE GEOTHERMAL WELL # 1

completion schematic



well completed July
1978

figure 8-1

NAVARRO COLLEGE GEOTHERMAL WELL #1

Well Head

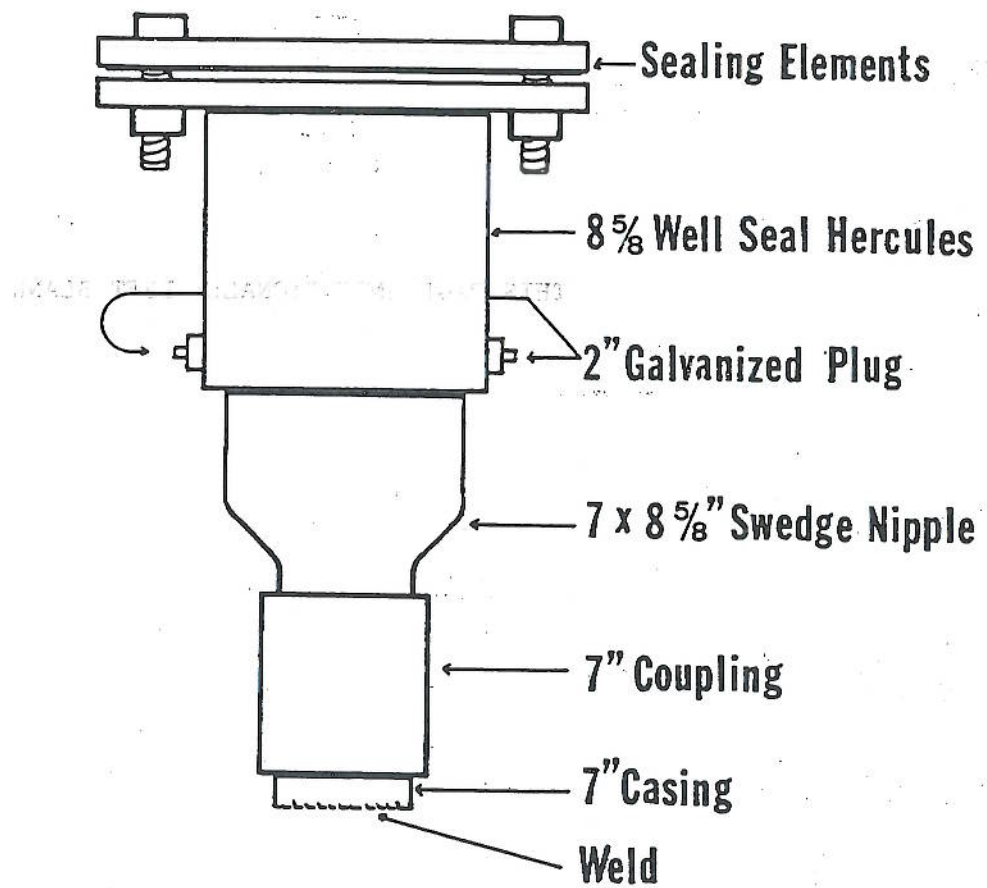


Figure 8-2

FIGURE 1-3
WATER TREATMENT

WATER TREATMENT

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9.0 RESOURCE TESTING

Production tests were performed during the summer of 1979. Results of these test are as follows:

- Static water level below ground surface (BGS).....421'
- Position of a TRW Reda 120 hp pump BGS.....1,000'
- Pumping rate - - gallons per minute (GPM).....315
- Drawdown BGS.....777'
- Water temperature at the surface.....125°F
- Estimated sustained maximum production (GPM).....400
- Average total dissolved solids (TDS).....± 6000 milligram per liter (mg/l)

The production well was reworked during the fall of 1980 and a more comprehensive test of the resource was performed on December 17, 18, and 19 of 1980 by two Radian Corporation hydrogeologists.

This test was used to define the well characteristics and aquifer parameters as listed in this section of the report. The results of this test were compiled and presented by Radian Corporation in a report entitled "Geothermal Injection and Production Well Results at Navarro College", February 14, 1981. A copy of this report may be obtained from the U.S. DOE Technical Information Office. A chemical analysis of the resource water is listed in the appendix.

9.1 Apparatus

A 40 horsepower submersible pump was installed in well number 1 and a temporary transformer installed to convert the available 1320 volts AC to 480 VAC required by the motor. Fifty feet of 3 inch PVC pipe was used to route the water over a small berm and away from the wellhead. Flow was controlled by a 2 inch gate valve at the wellhead.

A four foot section of 4 inch pipe with a 2 inch free discharge orifice was attached to the end of the PVC pipe and used to measure flow. A 0.0625 inch hole was drilled in the top face of the orifice plate in an attempt to vent evolved gases from the upstream 4 inch pipe section.

Water levels were measured by use of a copper air line placed in the production well and attached to a pressure gauge.

9.2 Test Conducted

Data from this test was used in determining aquifer parameters of transmissivity, coefficient of storage, cone of depression, specific capacity, discharge temperature, chemical quality, and presence of dissolved gases.

The pump was turned on and allowed to clean and develop the well for twelve hours on December 17 and 18. The flow rate during development exceeded 100 GPM but was less than 165 GPM. The pump was turned off at 3 a.m. on December 18, 1980 and the water level in the well permitted to recover.

Based on the data collected, a 19 hour drawdown specific capacity of 0.99 and an estimated 19 hour recovery specific capacity of 1.03 were calculated. The average value being 1.0 gallons per minute per foot of drawdown (GPM/ft. dd). The water levels during the 3.6 days of pumping are recorded and shown in the following table and show no significant change with additional pumping.

TABLE 9.2-1.

Date/Time	Pump Test Discharge Temperature (°F)	Time Since Pumping Began (Hours)	Pumping Water Level (Feet Below Measuring Point)
18 Dec. 1980			
6:00 PM	Pump turned on @100GPM	0	491
6:15	103.1		
:30	111.2		
:45	114.8		
7:00	116.6	1	570
:15	118.4		
:30	121.1		
:45	121.1		
8:00	118.4	2	571.5
:15	118.4		
:30	118.4		
:45	119.3		
9:00	118.4	3	578
:30	118.4		
10:00	120.2	4	580.5
:30	122.0		
11:00	122.9	5	586
:30	119.3		
12:00 Midnight	118.4	6	578
19 Dec. 1980			
12:30 AM	118.4	7	
1:00	118.4	7	580.5
:30	117.5		
2:00	116.6	8	581
3:00	116.6		
4:00	122.0	10	583
5:00	120.2		
6:00	122.0	12	585
7:35	122.0		

TABLE 9.2-1 (Cont.)

Date/Time	Pump Test Discharge Temperature (°F)	Time Since Pumping Began (Hours)	Pumping Water Level (Feet Below Measuring Point)
10:06	122.9	16	587
11:00	116.6		
12:00 Noon	122.9		
1:00 PM	122.9		
1:01	Pump turned off	19	588
10:00	Pump turned on for further well development @ ±100GPM		
21 Dec. 1980			
11:00 AM	123.8	37	586
22 Dec. 1980			
11:30 AM	123.8	61.5	596
23 Dec. 1980			
11:15 AM	123.8	85.5	596
12:00 Noon	Pump turned off end of pumping development		

Discharge Temperature During Navarro
College Geothermal Well Test
Table 9.2-1

The temperature of the discharging geothermal fluid was taken at hourly intervals during the course of the pump test and are also shown in Table 9.2-1. At the end of the 19 hour pump test, the discharge temperature was 122.9 degrees F but recovered in later tests to 123.8 degrees F.

During the test, field specific conductances were determined for pumped fluid samples and are presented in Table 9.2-2 along with dissolved gas notations. A water sample was collected on December 19,

1980 upon completion of the 19 hour test. Analysis of the sample for total dissolved solids (TDS) indicated a value of 6080 milligrams per liter (mg/l). Two previously recorded values of TDS were at 5300 mg/l and 6820 mg/l.

TABLE 9.2-2.

Date	Time	Hours of Pumping	Field Conductance (mhos/cm)	Conductance Sample Temperature (°F)	Remarks
12-18-80	7 P.M.	1	13,100	105.8	Clear discharge some gas bubbles.
	8	2	13,100	116.6	Clear discharge.
	9	3	13,400	114.8	Clear discharge.
	10	4	13,200	109.4	Clear discharge.
	11	5	14,000	110.3	Clear discharge, gas.
	12 mid.	6	15,000	112.1	Clear discharge with bubbles, distinct odor.
12-19-80	1 A.M.	7	14,500	113.0	Clear discharge.
	2	8	14,750	113.0	Clear discharge, lots of gas in discharge with distinct odor.
	3	9	15,000	104.0	Clear discharge, lots of gas in discharge with distinct odor.
	4	10	15,700	113.0	Clear discharge.
	5	11	15,500	113.0	Clear discharge.
	6	12	15,500	113.0	Clear discharge.
	8	14	15,700	112.2	Clear discharge.
	10.15	16.25	14,700	113.9	Clear discharge.
	12 Noon	18	15,500	114.8	Clear discharge.
	12:55	19	14,700	113.0	Clear discharge.
12-17-80	1 P.M.	19	End of Pumping Phase of Test		

Field Specific Conductances of Pumped Geofluids
Table 9.2-2

The computed average transmissivity value determined from the drawdown and recovery data of the 100 GPM test is 1360 gallons per day per foot (GPD/ft). This value is lower than the average Woodbine value of 2300 GPD/ft reported for Navarro County by the Texas Water Development Board, report number 160, but does not appear unreasonable as the production well is perforated only in the lower Woodbine formation of 81 feet average thickness. From this the average permeability is computed at 16.8 gallons per day per square foot (GPD/ft²) (0.449 Darcy).

The coefficient of storage (a dimensionless number) is the amount of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. This parameter assists in determining how rapidly a cone of depression will expand with time. The average storage coefficient value computed from the test was 0.000024. Calculations indicate that the cone of depression caused by the pumping at the production well migrated radially out to about 2 miles during the course of the test assuming a practical sensible drawdown of 0.01 feet. No apparent hydrogeological boundaries were noted during the course of the test.

9.3 Results

All test objectives were met during the pump test of Well number 1 and no additional development is required. The geothermal fluid temperature of 123.8°F was within 2°F of the Spring 1979 test and is adequate to provide heating requirements of the cascade geothermal aquaculture system.

10.0 DISPOSAL WELL DRILLING AND LOGGING

10.1 Summary

During December of 1979, a second exploratory well was drilled on Navarro College property to determine if a hotter resource, of better quality, could be encountered. This would allow use of the first well as an injection well.

The second well was drilled to a total depth of 4762 feet. An electric log (see Appendix C) was run in the open hole from a depth of 4762 feet to within 2500 feet of the surface where previous logs had been run on the first well.

Only poorer quality resources were encountered and the hole was plugged back to a final depth of 2400 feet for use as the injection well. The well was then completed with perforations in the upper Woodbine Formation.

10.2 Completion

Prior to testing the disposal well at 3900 feet, a string of 8-5/8 inch casing was set and cemented at 4163 feet. Fluid yield and quality from this zone was not acceptable and the well was initially plugged back to 3300 feet and completed in the lower Woodbine Formation by perforating from 2452 feet to 2590 feet.

Testing was initiated to determine if there would be any interference with well number 1. When pumping in well number 2 was started, an immediate drawdown was noted in well number 1.

Because of this interference, well number 2 was plugged back to a depth of 2400 feet on December 23, 1981, for use as the injection well.

After the plug was set, the well was perforated in the upper Woodbine Formation with 4 shots per foot in the intervals 2234 feet to 2256 feet and 2278^{ft} feet to 2292 feet. A total of 36 feet of sand was perforated with 133 shots.

A standard non-pressure wellhead was installed (Fig. 10-1)

10.3 Stimulation Method

In an effort to increase the rate at which the disposal well would accept fluids at a low pressure, a hydraulic fracture treatment was performed on the upper Woodbine Formation sands on October 23, 1981. The method employs hydraulic pressure to fracture the rock and the introduction of sand into the fractures, preventing their closing after the pressure is released.

The formation broke down at a surface pressure of approximately 1500 pounds per square inch (PSI). Before all the sand could be pumped into the fractures, the formation quit taking the sand leaving a sand-gel mixture in the casing. The sand settled out of the gel and filled the casing to a point above the perforations.

On October 24, 1981, a coiled tubing unit was used to run a 1 inch outside diameter (O.D.) continuous tube into the well and nitrogen was employed to jet-lift the sand out of the casing. The sand was removed to a depth of 2309 feet, clearing all perforations.

NAVARRO COLLEGE GEOTHERMAL WELL #2

WELL HEAD

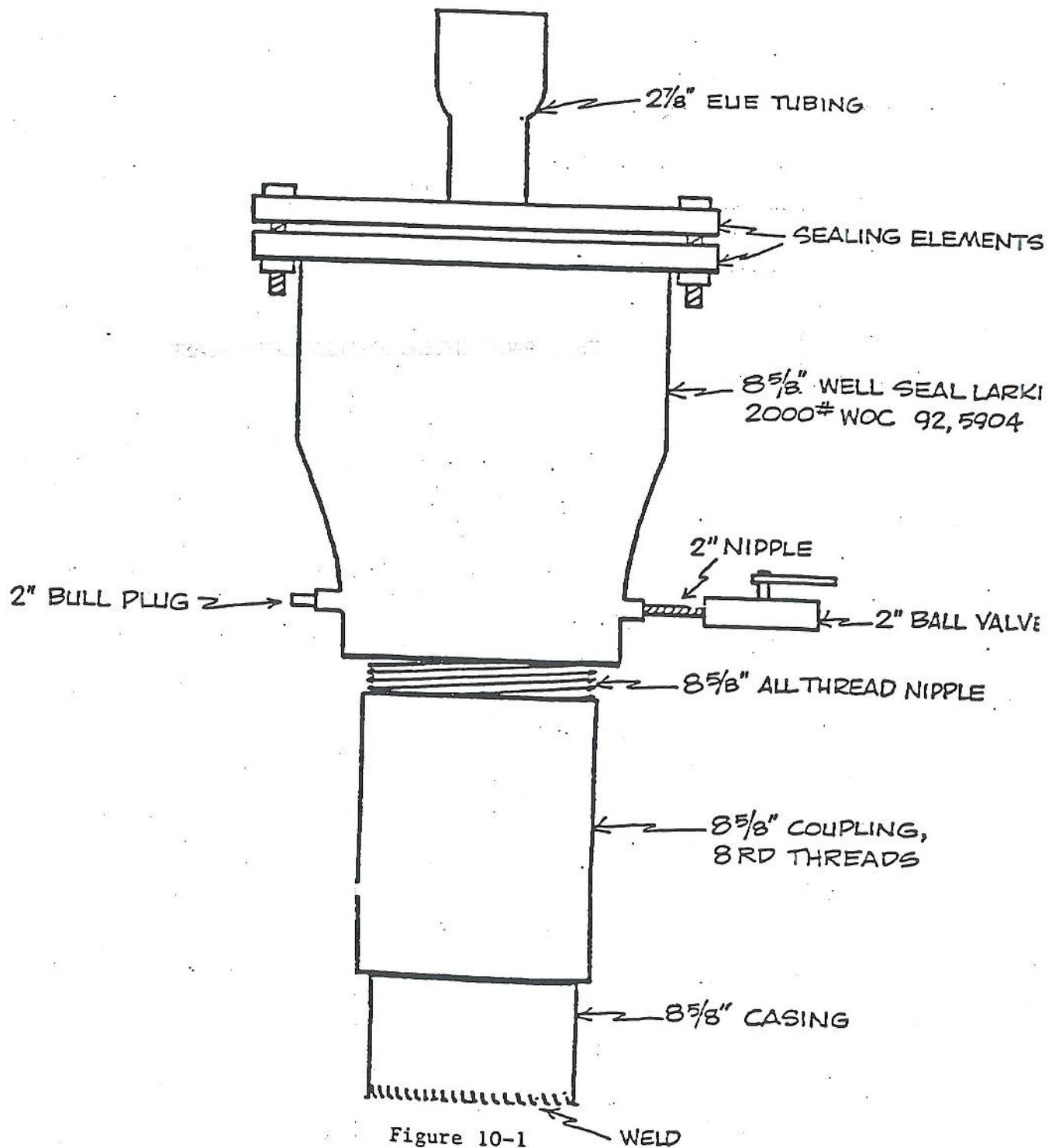


Figure 10-1

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11.0 DISPOSAL TESTING

On October 24, 1981, a pump truck was connected to the disposal well and water from a holding tank was pumped into the well. Pumping began at the rate of 255 GPM per minute at a constant pressure of 750 pounds. After 20 minutes of pumping at 750 pounds of pressure an attempt was made to determine the acceptance rate at gravity feed. A gravity injection rate of only 60 GPM was obtained. It was also determined that 500 pounds of pressure would be required to sustain an acceptance rate of 120 GPM.

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12.0 APPLICATION ANALYSIS

12.1 Technical

The Geo-Heat Center at Oregon Institute of Technology was given the limitation of the injection well and requested to determine the most feasible application for this resource. Preliminary engineering and design details performed by the Geo-Heat Center indicated that the most feasible application would be in an aquacultural/agricultural operation.

The Geo-Heat Center was provided with information on average daily, monthly, and yearly temperatures at Corsicana, Texas, plus an expected energy yield from the resource of 1.6×10^6 BTU/HOUR at 60 GPM flow and they determined that sufficient energy was available to maintain 0.5 acres of covered aquaculture ponds at an optimum prawn growing temperature of 82°F. In addition to the aquaculture operation, the center advised that sufficient energy would exist in the effluent from these ponds to provide necessary heat for space heating requirements of a small greenhouse unit.

In an effort to increase the economic viability of the project, it was determined that all effluents could be captured in a two acre reservoir which could be utilized for a catfish production pond and possible irrigation of cropland.

With this preliminary engineering data available, Navarro College submitted a supplement to the original proposal in December of 1981 to the United States Department of Energy which received approval through Modification A005 to the original proposal, "Direct Utilization of Geothermal Energy at Navarro College, Corsicana, Texas".

This approval led to preparations of preliminary and Final Design Reports by a certified Architectural/Engineering Firm which were approved through the Department of Energy. These reports reflect a project that has been engineered as technologically feasible.

12.2 Economic

A preliminary economic analysis of the project was conducted by determining the projected income of all crop items from the research project plus potential income from new student enrollment due to incorporation of project elements into the Navarro College curriculum.

Due to the limited size of the project on campus property, and because of the restricted injection rate, it was recognized that this would be a pilot project only. As a pilot research project, a payback on investment was not calculated as it would be for a much larger commercial operation.

The chart below reflects a plot of the projected annual income from crop items and student enrollment income compared to the projected annual expenses for the first year of operation.

<u>PROJECTED ANNUAL INCOME</u>		<u>PROJECTED ANNUAL EXPENSES</u>	
Prawns - $\frac{1}{4}$ A x 4000 lbs./A/Yr.		Personnel:	
= 1000 lbs. x \$8./lb.	\$ 8,000.	1 FTE Aquaculturist	\$26,000.
Catfish - 2A x 1500 lbs./A		1 $\frac{1}{4}$ FTE Secretary	3,600.
= 3000 lbs. x \$1.25/lb.	3,750.	2 Pt. Time Laborers	3,700.
Greenhouse Produce -		Other Personnel Expenses	8,000.
10,000 lbs. x \$.50/lb.	5,000.	Utilities:	4,000.
New Student Enrollment:	40,000.	Maintenance:	1,500.
		Communications:	1,500.
		Supplies:	5,000.
<hr/>		<hr/>	
TOTAL ESTIMATED INCOME	\$56,750.	TOTAL ESTIMATED EXPENSES	\$53,300.

These income figures are based on a low end of production and student enrollment and would be considerably higher if yields and enrollment were greater.

13.0 OBTAINING USER COMMITMENT

* No users other than Navarro College.

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14.0 SYSTEM LOADS

This section describes the projected heating and cooling requirements of the project as calculated by an independent engineering firm.

Due to the nature of the project being exploratory and research oriented, very little data was initially available on heating and cooling requirements for aquacultural purposes in this area. Therefore, a vital part of this report has been directed at determining if calculated demands and flows would prove sufficient in this type of application.

14.1 Calculated Heating and Cooling Requirements

In designing the heating system for this project a calculation was determined on the maximum probable heat loss from the aquaculture ponds and greenhouse during a peak demand period. The heat losses experienced in this project consist of (1) heat transmitted through the walls, roofs, and other surfaces and (2) the heat required to warm outside air entering the heated space.

Heat loss for an area is computed by the equation $Q=UA (T_i-T_o)=UA \Delta T$

where:

Q = heat transfer rate from one area to an adjacent area (pond to air or air to building, etc)

U = heat transfer coefficient (BTU/Hr-ft²-°F)

A = heat transfer surface area (ft²)

ΔT = temperature difference between areas (°F)

This equation allows for calculation of heating or cooling requirements of each of the project elements listed below:

- A. Aquaculture ponds heat loss
- B. Aquaculture ponds heating water
- C. Heat exchanger parameters
- D. Aquaculture ponds heat gain during heating period
- E. Aquaculture facility ventilation rate
- F. Pond heat gain during cooling period
- G. Greenhouse heat loss and potential heat gain from pond effluents

A. AQUACULTURE PONDS HEAT LOSS

Enclosure Dimension - 204 ft. x 82 ft. x 12 ft.

$$\text{Total Exposed Area } (A_1) = 2 (82 \times 12) + 2 (204 \times 12) + (204 \times 82)$$

$$A_1 = 1,968 \text{ ft}^2 + 4,896 \text{ ft}^2 + 16,728 \text{ ft}^2$$

$$A_1 = 23,592 \text{ ft}^2$$

Pond Dimensions - 185 ft. x 30 ft. x 4 ft.

$$\text{Total Pond Surface Area } (A_2) = 2 \times 185' \times 30'$$

$$A_2 = 11,100 \text{ ft}^2$$

Heat loss to sides and bottom of pond.

$$\begin{aligned} \text{Total Bank Area} &= (4 \times 185 \times 4) + (4 \times 30 \times 4) \\ &= 3,440 \text{ ft}^2 \end{aligned}$$

Value of $T_{\text{water-bank}} = 25^{\circ}\text{F}$

$$U_{\text{Bank}} = 0.8 \text{ BTU/Hr-ft}^2\text{-}^{\circ}\text{F}$$

Let Q_3 = Heat Loss to Bank

$$Q_3 = 0.8 \times 25^{\circ}\text{F} \times 3,440 \text{ ft}^2$$

$$Q_3 = 68,800 \text{ BTU/Hr}$$

At equilibrium conditions, the pond heat loss will equal that of the enclosure heat loss.

Let Q_1 = Enclosure Loss

Q_2 = Pond loss to enclosure space

$T_o = 17^{\circ}\text{F}$ Temp. outside (peak demand)

T_i = Temp. inside

$T_p = 82^{\circ}\text{F}$ Pond temp.

$$Q_1 = U_1 \times A_1 \times (T_i - T_o)$$

$$Q_2 = U_2 \times A_2 \times (T_p - T_i)$$

$$U_1 \times A_1 \times (T_i - T_o) = U_2 \times A_2 \times (T_p - T_i) \dots \text{Pond loss} = \text{Enclosure loss}$$

$$U_1 A_1 T_i - U_1 A_1 T_o = U_2 A_2 T_p - U_2 A_2 T_i$$

$$U_1 A_1 T_i + U_2 A_2 T_i = U_2 A_2 T_p + U_1 A_1 T_o$$

$$T_i = \frac{U_2 A_2 T_p + U_1 A_1 T_o}{U_1 A_1 + U_2 A_2}$$

$$U_1 A_1 + U_2 A_2$$

$$U_1^* = 1.0 \text{ BTU/Hr-ft}^2\text{-}^{\circ}\text{F}$$

$$U_2^* = 1.0 \text{ BTU/Hr-ft}^2\text{-}^{\circ}\text{F}$$

* Source: White, Frank M. "Heat Transfer" copyright 1984 by Addison-Wesley Publishing Co., Inc.

$$T_i = \frac{(1 \times 11,100 \text{ Ft}^2 \times 82^\circ\text{F}) + (1 \times 23,592 \times 17^\circ\text{F})}{(1 \times 11,100 \text{ Ft}^2) + (1 \times 23,592)}$$

$$T_i = 37.8^\circ\text{F}$$

$$Q_2 = U_2 \times A_2 \times (T_p - T_i)$$

$$Q_2 = 1 \times 11,100 \times (82 - 37.8)$$

$$Q_2 = 490,620 \text{ BTU/Hr}$$

$$\text{Total Loss} = 490,620 + 68,800$$

$$= \underline{559,420 \text{ BTU/Hr}}$$

This calculation has assumed no infiltration loss and therefore the actual load will be somewhat higher.

B. AQUACULTURE PONDS HEATING WATER REQUIRED

$$\text{Pond Heat Loss} = 559,420 \text{ BTU/Hr} = 559,420 \text{ lb/hr-}^\circ\text{F} \times \frac{1 \text{ gallon}}{8.34 \text{ lb.}}$$

$$\frac{60 \text{ min/hr}}{8.34 \text{ lb.}}$$

$$\text{Heating Water Required} = \frac{\text{HEAT LOSS}}{500 \times \Delta T \text{ Geo-pond}^*}$$

(freshwater)

$$\begin{aligned} &= \frac{559,420}{500 \times 33^\circ\text{F}} \\ &= \underline{34 \text{ GPM}} \end{aligned}$$

* Projects heating water enters at 115°F and pond temp is @ 82°F

C. HEAT EXCHANGER PARAMETERS

Geothermal water temp. entering exchanger = 125°F

Geothermal water temp. leaving exchanger = 70°F

Fresh water temp. entering exchanger = 62°F

Fresh water temp. leaving exchanger = 115°F

$$\text{Geothermal Heat} = 35 \text{ GPM} \times 500 \times (125 - 70)$$

$$= 962,500 \text{ BTU/Hr}$$

$$\text{Freshwater GPM} = \frac{962,500 \text{ BTU/Hr}}{500 \times (115-62)}$$

$$= \underline{\underline{36 \text{ GPM}}}$$

D. AQUACULTURE PONDS HEAT GAIN DURING HEATING PERIOD

Heat gain = Solar gain + Transmission

$$\text{Exposed Area} = \begin{array}{l} \text{N} - 204 \times 9 = 1836 \\ \text{E} - 82 \times 9 = 738 \\ \text{S} - 204 \times 9 = 1836 \\ \text{W} - 82 \times 9 = 738 \\ \text{Hor} - 204 \times 82 = 16,728 \end{array}$$

$$\text{Solar Gain Factors} = \begin{array}{l} \text{N} - 30 \text{ BTU/Hr-Ft}^2 \\ \text{E} - 77 \\ \text{S} - 72 \\ \text{W} - 90 \\ \text{Hor} - 205 \end{array}$$

$$\text{Solar Gain} = 1836 (30 + 72) + 738 (77 + 90) + 16,728 (205)$$

$$= 187,272 + 123,246 + 3,429,240$$

$$= \underline{\underline{3,739,758 \text{ BTU/Hr}}}$$

$$\text{Transmission Gain} = (2 \times 1836) + (2 \times 738) + 16,728 \times$$

$$1.0 \text{ BTU/Hr} - \text{Ft}^2 - ^\circ\text{F} \times 20^\circ\text{F}$$

$$= \underline{\underline{437,520 \text{ BTU/Hr}}}$$

$$\text{Total Gain} = 3,739,758 + 437,520$$

$$= 4,177,278 \text{ BTU/Hr}$$

E. AQUACULTURE FACILITY VENTILATION RATE

$$\text{Total Heat Gain} = 4,177,278 \text{ BTU/Hr}$$

If a max. temp. rise of 20°F in the aquaculture building is allowed,

$$\text{Vent rate} = \frac{4,177,278}{1.08 \times 20^\circ\text{F}} = 193,392.5 \text{ CFM}$$

$$\begin{aligned} 10 \text{ Fans used} &= 193,392.5 \div 10 \\ &= 19,340 \text{ CFM/FAN} \end{aligned}$$

F. POND HEAT GAIN DURING COOLING PERIOD

Assuming enclosure temp. is 120°F and water temp. is 82°F with an h-value of 1 BTU/Hr-Ft²-°F

$$\begin{aligned} \text{Pond Heat Gain} &= h \times A \times T \\ &= 1 \times 185 \times 60 \times 20 \\ &= 222,000 \text{ BTU/Hr} \end{aligned}$$

$$\text{Cooling water flow required} = \frac{\text{Heat gain}}{500 \times \Delta T}$$

$$\begin{aligned} \text{Cooling water} &= 222,000 \quad (500 \times 20) \\ &= \underline{\underline{25 \text{ GPM}}} \end{aligned}$$

G. GREENHOUSE HEAT LOSS AND POTENTIAL HEAT GAIN FROM POND EFFLUENT

$$\text{Enclosure area} = 30' \times 108'$$

$$\begin{aligned} \text{Surface area} &= N (2 \times 8' \times 108') + (2 \times 10' \times 30') + (30 \times 108) \\ &= 1728 + 600' + 3240 \\ &= 5568 \text{ Ft}^2 \end{aligned}$$

With a U-Factor of 1 BTU/Hr-Ft²-°F and a 30°F temp. difference (20° outside 50° inside)

$$\begin{aligned} \text{Heat Loss} &= 1 \times 5568 \times 30 \\ &= 167,040 \text{ BTU/Hr} \end{aligned}$$

Pond effluent temp. of 80°F and a flow at 30 GPM with a delta T through the Greenhouse Heaters.

$$\begin{aligned}\text{Available heat} &= 30 \text{ GPM} \times 500 \times 10 \\ &= 150,000 \text{ BTU/Hr}\end{aligned}$$

Due to additional infiltration loss, the Greenhouse will require additional heating but sufficient heat should be available for Spring and Fall heating requirements.

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15.0 PRODUCTION SYSTEM DESIGN

The production system of the Navarro College Geothermal Project includes the production well, the submersible pump and its control system, and the associated geofluid valving and piping to the heat transfer system located in the mechanical equipment building.

15.1 Materials Selection

The water quality, as presented in Table 15-1, was a critical factor that the project's architectural/engineering firm considered in properly designing the system.

TABLE 15-1

Constituent	Sample #1 (mg/l)	Sample #3 (mg/l)	Drinking Water Stds. (mg/l)	Irrigation Stds. (mg/l)
Total Dissolved Solids	6820	5300	500	5000
SO ₄ ⁻	2.4	38	250	-
Cl ₂ ⁻	3520	2560	250	-
F ₂ ⁻	1.6	-	2.4	1.0
HCO ₃ ⁻	-	1140	-	-
Na ⁺	1200	2020	-	-
Ag ⁺	.007	-	0.05	-
Si	11	-	-	-
Se ₂ ⁺	.005	-	0.01	-
Hg ₂ ⁺	.0005	-	0.002	-
Mg ₂ ⁺	-	5.6	-	-
Pb ₂ ⁺	.003	-	0.05	5.0
Fe ₂ ⁺	1.1	-	0.3	5.0
Cr ₂ ⁺	.005	-	0.05	0.10
Ca	-	13	-	-
B	14	-	-	-

Navarro College
Geothermal Water Quality Analysis
Table 15-1.

The geothermal water system, the freshwater transfer heating system, and greenhouse heating system needs were discussed with the A/E firm and with the McCormick Corporation, Water Treatment Specialists in Dallas, Texas, in an effort to eliminate any possible problem areas with facility operations.

Table 15-2 lists the components and selected materials recommended by the engineers.

TABLE 15-2

Component	Material Selected
Production and Injection piping (in the wells)	2 3/8" downhole tubing coated with an interior acrylic resin
Surface Piping (hot)	Schedule 80 CPVC
Surface Piping (cool)	Schedule 40 PVC
Valves	Rated 125 psi WSP each having a bronze body, with rising stem, solid wedge of ASTM Designation B-61 bronze, standard packing with bronze gland follower, and malleable iron wheel.
Pump Bowls	Flanged and bolted type made of close-grained cast iron. Flanges are of sufficient cross-section to prevent deflection, and are reinforced with four ribs (minimum), which are at least one-half the flange metal thickness. The diffuser portion of the bowl casting has a maximum cross-section to insure long life. Threaded bowl connections are not supplied but are provided with replaceable wear rings of SAE 64.
Pump Shaft	Made of AISI 416 Stn. Stl., rolled or forged, ground and sized to provide minimum deflection.

Pump Impellers

Enclosed type of bronze, secured to the shaft with SAE 1213 steel tapered deflection.

Plate Heat Exchanger

Gasket material of nitrile and flush-fitted design. Plate material of Type 304 stainless steel, not less than 0.6mm in thickness. Heat exchanger meets the requirements of applicable ASME and ANSI Codes and Standards, including the ASME Code for Unfired Pressure vessels, for which inspection, stamping and certification has been provided. Heat exchanger to be a unit consisting of an assembly of plates with flush-fitted gaskets supported in frames capable of being opened and reclosed, fitted with nozzles or ports that provide entrance and exit for the two heat exchanging fluid streams, and fitted with a special system of gas evacuation checks to prevent gas-vapor locking.

Navarro College
Geothermal Project Materials Selection
Table 15-2.

By using these materials for each of the project elements only minor scaling and corrosion have been noted during routine maintenance.

15.2 Production System Design

A schematic of the Navarro College geothermal production system is presented in Figure 15-1.

This system is composed of the production pump and controls, the downhole tubing, the CPVC piping, and the plate heat exchanger.

The production pump is a TRW Reda, multi-stage 540 series, submersible unit, with a low water level protector. It has been set on 660 feet of 2-3/8 inch tubing and has a pumping capacity of 30 gallons per minute.

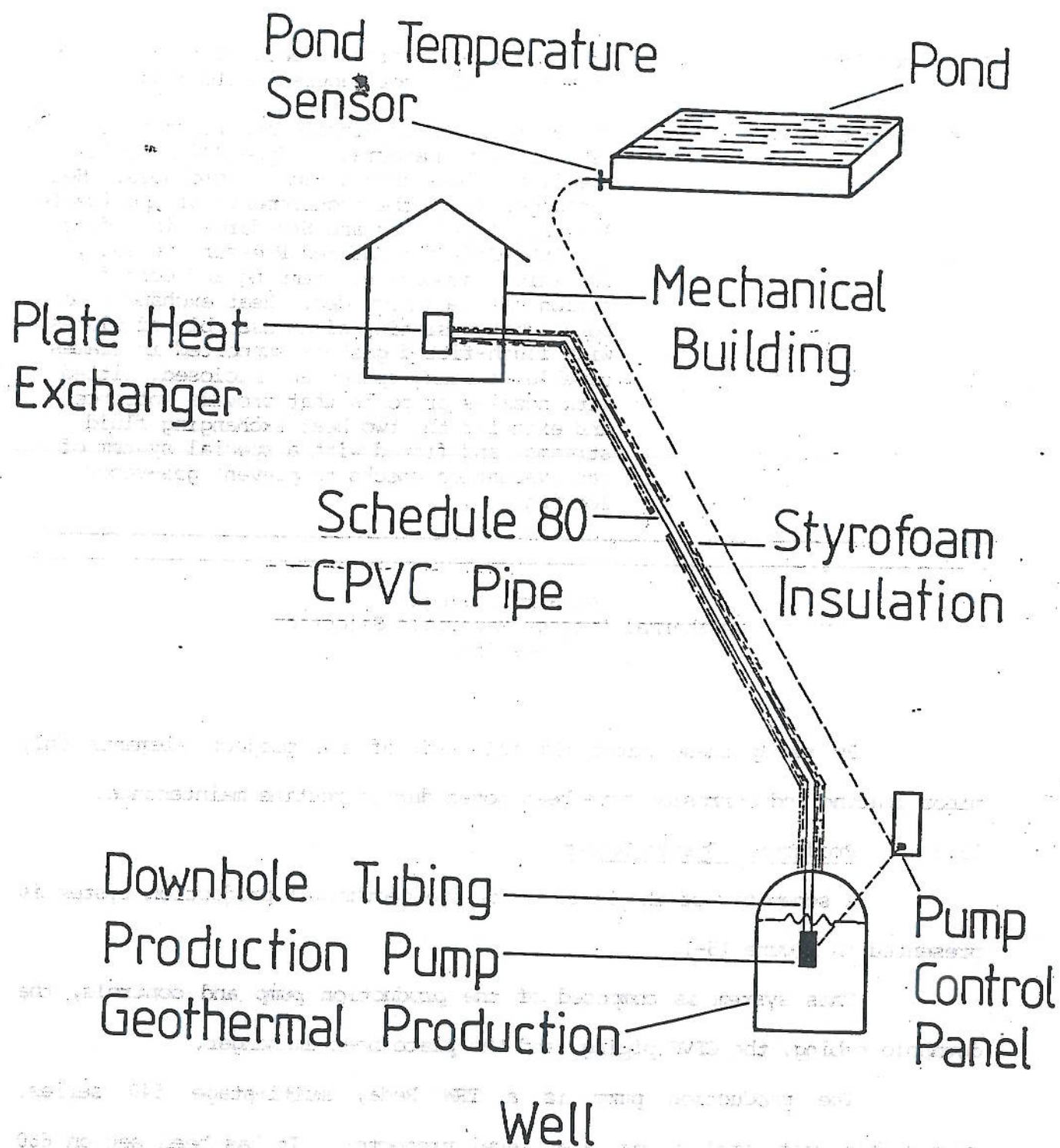


Figure 15 - 1
Geothermal Production
System

The project has been designed so that all controls operate in an automatic on or off mode. This was accomplished by setting a 3°F differential in the shrimp pond temperatures. A pond temperature decrease to 79°F will activate the geothermal pump by means of a relay from the thermostats, and will then shut the pump down when the pond temperature has reached 82°F.

An ammeter chart is mounted in the pump control panel and provides a continuous record of pump on and off time. This plus the pump rate of 30 gallons per minute, provides the amount of energy used by the project during peak and non-peak demand periods.

Downhole tubing consists of 2-3/8 inch steel pipe coated on the interior with an acrylic resin to reduce scaling and corrosion problems.

The production line from the well to the mechanical building, where the plate heat exchanger is located, is Schedule 80 CPVC pipe. This type of pipe is resistant to scaling and higher (135°F) temperatures of the geothermal fluids. This line has also been covered with one inch of styrofoam insulation to reduce heat loss from the well to the plate heat exchanger.

The plate heat exchanger, a Baltimore Aircoil plate and frame unit measuring 5 feet by 1.5 feet by 0.5 feet, has plates composed of Type 304 Stainless Steel to reduce corrosion and scaling. This unit transfers the heat from the geothermal fluid to the freshwater which is used for project heating requirements.

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16.0 DISPOSAL SYSTEM DESIGN

An injection well was required by state regulating authorities to avoid ground water contamination from the spent geothermal fluids (See Section 6.2). It was established through preliminary injection testing that this well would accept sufficient fluids at gravity flow to meet project demands (Section 10).

16.1 Materials Selection

In order to protect potential potable ground water aquifers and reduce corrosion of the casing in the injection well, tubing and a packer was installed. This unit (a Baker Packer - Model-1A) was set at 2200 feet and the 2-3/8" injection tubing was stabbed into it. This tubing was coated on the interior with an acrylic resin to reduce downhole scaling and corrosion. Piping from the plate heat exchanger to the injection well is Schedule 40 PVC (See Figure 19-1).

16.2 Design

Design of the disposal system is simple in concept:

Cool geothermal fluids (60° - 80°F) leaving the plate heat exchanger, exit the Mechanical Equipment Building through 2 inch schedule 40 PVC pipe to the injection well (approximately 300 feet). The fluid then enters the injection well head in the 2-3/8" down-hole steel tubing, gravity flows from the well head past the packer unit, through the perforations in the well wall, and into the Upper Woodbine Formation.

A pressure gauge is mounted at the well head in the 2-3/8" tubing. When salts begin to impede the flow of fluids into the formation, it will register on the pressure gauge.

Treatment of the injection well with 100 pounds of citric acid dissolved in water has been successful in removing these salt formations.

17.0 TRANSMISSION SYSTEM DESIGN

All aspects of the project are confined to a small location on one portion of the College campus area, this section of the report is not applicable to the Navarro College system.

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18.0 DISTRIBUTION SYSTEM DESIGN

Navarro College is the sole user of this resource and the production and disposal wells are located on their premises, therefore this section is not applicable.

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19.0 APPLICATION SYSTEM DESIGN

The application system for the Navarro College Geothermal Project was designed to utilize the maximum amount of available energy by cascading it through several uses.

This system consists of the heat energy transferred from the geothermal fluid to a fresh water source which is used for aquacultural and agricultural crop production.

19.1 Design

Based upon preliminary design concepts, the project's architectural engineers prepared a final design package for the project. In this system, shown schematically in Figure 19-1, geothermal fluids are pumped from the production well through the plate heat exchanger to heat fresh water. The cooled geothermal fluids then flow to the injection well.

The heated fresh water flows through a flow meter in the mechanical building which monitors instantaneous and cumulative flows to the enclosed shrimp ponds. Continuous records of geothermal and fresh water temperatures are maintained on strip chart recorders with thermocouple connections to the inflow and effluent pipes of the plate heat exchanger.

When shrimp pond temperatures decrease to 79°F, inflow valves open and the geothermal pump is activated. This allows heated fresh water to flow into the shrimp ponds until pond temperatures have increased to 82°F, at which time pond inflow valves close and the geothermal pump is deactivated. Constant records of pond temperatures are also retained on strip chart recorders.

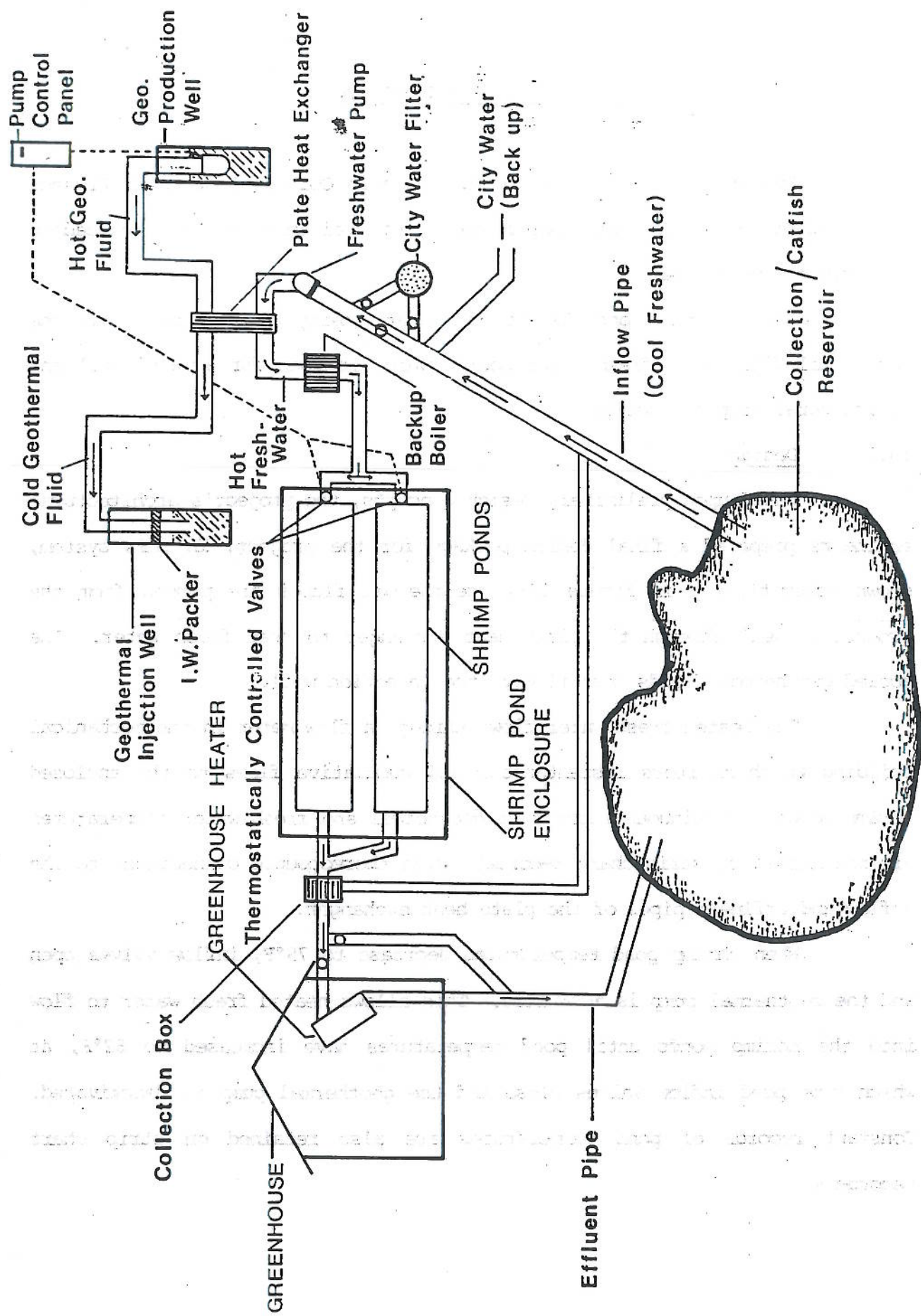


Figure 19 - 1

Navarro College Geothermal Project